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THUNDERSTORM TURBULENCE INVESTIGATIONS FOR 1973 - 1974 IN SUPPORT OF THE NATIONAL STORMS LABORATORY (NSSL)

4950TH TEST WING

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December 1978

Final Report for Period May - June 1973 and April - June 1974

Prepared for

The National Severe Storms Laboratory
1313 Halley Circle
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4950TH TEST WING
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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During May and June of 1973 the 4950th Test Wing supplied an F-100F Thunderstorm Penetration aircraft to take turbulence measurements in support of a National Severe Storms Laboratory Program designed to evaluate doppler radar as a means of detecting and quantifying turbulence areas and intensities within severe storms. The tests were flown out of Tinker AFB, Oklahoma. The program was continued the following year during the Oklahoma thunderstorm season, April-June 1974. For the second year an RF-4C was used as a penetration aircraft. This report presents the vertical wind and derived gust velocity experience accumulated during these

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two seasons and correlates them with statistical parameters, radar reflectivity, gradient of radar relectivity, etc. An attempt is made to determine if variations of the correlation coefficients relating these various quantities exhibits a trend as altitude is increased or decreased. The results are not conclusive.

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SECTION I

INTRODUCTION

1. The National Severe Storms Laboratory (NSSL) conducted a thunderstorm turbulence investigation during May and June of 1973. The NSSL is a part of the National Oceanic and Atmospheric Administration (NOAA). The purpose of the investigation was to evaluate a radar display known as a "plan shear indicator" and to obtain additional data on turbulence within thunderstorms using an experimental Doppler radar. The plan shear indicator was developed by the Air Force Cambridge Research Laboratory (AFCRL), and, when attached to a Doppler weather radar unit, provides a visual indication of the presence of shear in the radial component (relative to the antenna) of the horizontal wind in storms.

2. To accomplish the investigation, NSSL requested support from the United States Air Force in the form of a suitable thunderstorm penetration aircraft. The aircraft was needed to fly through those areas of storms where the plan shear indicator detected horizontal wind shear in order to obtain quantitative measurements of actual turbulence levels.

3. The flight test portion of the program was conducted by the 4950th Test Wing, Aeronautical Systems Division, Air Force Systems Command, United States Air Force. The plan shear indicator was located at the NSSL installation at Norman, Oklahoma which is 20 miles south of Tinker Air Force Base. The test aircraft operated from Tinker Air Force Base for the duration of the program.

4. The thunderstorm turbulence investigation continued in April and May of 1974. The reason for the continuation was the need to collect a sufficiently large quantity of data to assure statistical significance. Past experience has indicated that at least three years of data gathering are required to reduce the probability of bias. Operating procedures were similar to those used in 1973 but NSSL added a second Doppler radar and eliminated the plan shear indicator in favor of a different type of display generated by a device called a "mean velocity processor". The two Doppler radar units were separated by a distance of approximately 30 miles. Both units were focused on the same storm so that horizontal velocities within the storms could be resolved in a 2-dimensional coordinate system. By coordinating antenna tilt sequences and then integrating the stacked horizontal profiles obtained thereby the vertical velocities could be resolved making the coordinate system 3-dimensional.

5. Lack of correlation and trending makes it impossible to draw specific conclusions from the data sample. The purpose of this document is to make the methodology and the results available to future investigators of turbulence phenomena.

SECTION II

OBJECTIVES

1. The objectives of the 1973 test program were to record:

   a. The magnitude and distribution of turbulence in and near thunderstorms.

   b. Turbulence levels in areas of large horizontal wind variance per sample volume as measured by the NSSL doppler radar.

   c. Turbulence levels in areas of strong shear in the horizontal wind as indicated by the AFCRL plan shear indicator installed on the NSSL doppler radar.

2. The major emphasis of the 1973 program was to determine if the plan shear indicator would provide dependable indications of turbulence within storms and, if so, to correlate the intensity of the turbulence with the type of indication given. (If the device were to prove feasible it would have potential application to air traffic control work. For instance, a controller could examine a squall line to determine the location and intensity of turbulence areas and then vector aircraft through it safely.)

3. The objectives of the 1974 test program were the same as for 1973 with the exception of those items pertaining to the plan shear indicator (paragraph 5c) which was deleted for 1974.

SECTION III

TEST ITEM AND INSTALLATION

1. For 1973 the test items were the AFCRL plan shear indicator and the NSSL Doppler radar set on which it was installed. The purpose of the plan shear indicator was to provide a visual representation of variations in horizontal wind velocity (in the radial direction relative to the radar antenna) in thunderstorms. Essentially, the indicator functions in the following manner:

a. The Doppler radar measures the radial velocity component (relative to the antenna) of particles in the storm (drops of water, ice crystals, etc.). If there are no particles present no radar return is received.

b. The plan shear indicator generates a series of segmented lines around the face of the display tube, each segment corresponding to a small volume of space sampled by the doppler radar. The position of each line segment within its sample volume is determined by the magnitude and direction of the average radial velocity component within that particular volume. A significant difference in average radial velocity, between two adjacent volumes of space, results in a discontinuity or waviness in the lines on the scope and indicates the presence of horizontal shear. If there were no net velocity difference between sample volumes, the presentation on the scope would be a series of concentric circular arcs, wherever storms were present.

2. For 1974 the test items were the two experimental Doppler radar units and their display systems.

SECTION IV

TEST AIRCRAFT

1. In 1973 the test aircraft was F-100F S/N 56-3744. This same aircraft had been used in several previous thunderstorm penetration programs. Modifications to the aircraft included:

a. Installation of a special nose boom in place of the standard nose boom. This special boom was much stiffer than the standard boom and possessed a higher natural frequency. The increased stiffness was needed to reduce deflections of the angle-of-attack vane caused by bending of the boom during flight in turbulence.

b. Installation of a recorder and various other instrumentation components in the aft cockpit, both gun bays, and both expended link bays.

c. Installation of lightning-diverters and static dischargers on the wing and empennage trailing edges. Lightning diverters were also mounted on the wing tips and the tip of the vertical stabilizer.

d. Installation of pilot-selected engine continuous ignition.

2. In 1974 the F-100F used in previous programs was not available since it had been retired to Davis-Monthan Air Force Base. Therefore, another test aircraft, RF-4C S/N 63-7744, was selected. Modifications to the aircraft were generally the same as those to the F-100 except for the locations of the equipment. The tape recorder and signal-conditioning electronics were installed in the nose camera bay rather than the aft cockpit. The time code generator and the recorder controls were installed in the aft cockpit.

SECTION V

INSTRUMENTATION

1. For 1973 the following parameters were recorded on a Leach magnetic tape recorder:

   a. Angle-of-attack

   b. Pitch attitude

   c. Pitch rate

   d. Normal acceleration (at the c.g.)

   e. Altitude

   f. Airspeed

   g. Total temperature

   h. Stabilator position

   i. Event

   j. Time

   k. Voice

2. For 1974 roll attitude was added to the parameter list, which was otherwise the same.

SECTION VI

TEST PROCEDURES

1. Prior to deployment of the test aircraft to the test site in 1973, a pacer mission was flown to calibrate the pitot-static system and determine the change in position error caused by installation of the modified nose boom.

2. Upon arrival at the test site the following set of procedures were employed to coordinate and execute test missions:

a. At 1500 hours each day a call was made to NSSL to obtain a thunderstorm forecast for the following day. If there was any probability of storms in the test area, the task force was placed on alert status.

b. At 1100 hours the next day NSSL was contacted for an estimated takeoff time. This takeoff time was usually based on the best estimate of when suitable storms would actually begin to form.

c. Thirty minutes prior to the estimated takeoff time another call to NSSL was made. If the storms had developed as expected, a go-ahead was given and both the test and chase aircraft launched as planned. However, if storm development was lagging, a new estimated takeoff time was given. Thirty minutes prior to the new takeoff time another check was made, etc. This procedure was repeated until a successful takeoff was accomplished or until 90 minutes before local sunset, at which time further operations were cancelled.

d. Following takeoff the test and chase aircraft joined up and proceeded in formation to the target storm. As soon as possible after takeoff the formation received a hands-off from Oklahoma City Departure Control to Rough Rider Control which provided vectors to the target storm, or storms, and controlled the actual penetrations. Rough Rider Control was located in the radar room of the NSSL installation at Norman, Oklahoma.

e. Upon reaching the target storm the chase aircraft was placed in a holding pattern in the clear. The pilot of the test aircraft initiated a 15-second automatic calibration cycle of the instrumentation and performed a sinusoidal maneuver about the pitch axis for instrumentation polarity checks and function checks.

f. The test aircraft received a final penetration vector from Rough Rider Control at least one minute before storm entry and no further heading changes were permitted.

g. Penetration speed was 275 KIAS. The pilot endeavored to maintain aircraft attitude with as few control inputs as possible. He was to report storm entry and exit, turbulence and rain intensity, strong gusts, lightning, hail, icing, and other pertinent data on the voice channel of the tape recorder, and to make appropriate event marks when these things occurred.

h. The test aircraft continued straight and level for one minute following exit from the storm, after which another calibration cycle was run.

i. Following the last penetration the test and chase aircraft joined formation and returned to Tinker Air Force Base.

3. The same procedures were used for 1974 except for the thunderstorm penetration speed which was 300 KIAS for the RF-4C.

SECTION VII

DATA REDUCTION - 1973

1. The data tapes from each flight were converted to digital form at a rate of 50 samples per second. The data was then smoothed using a five point running average and digitized at a rate of 10 samples per second. From the smoothed data a partial printout was made for editing purposes. Editing consisted of locating those portions of data which required complete reduction (i.e. penetrations, sinusoidal maneuvers, etc.) and checking them for obvious errors or instrument malfunctions.

2. After initial editing was complete calibrations were applied and the data was processed at a rate of 10 samples per second. Values of vertical wind velocity and derived gust velocity were computed. The following parameters were tabulated at a rate of 10 samples per second:

a. NSSL time

b. Aircraft time

c. Angle-of-attack

d. Pitch attitude

e. Pitch rate

f. Normal acceleration (c.g.)

g. Altitude

h. True Airspeed

i. Total air temperature

j. Stabilator position

k. Vertical wind velocity

l. Derived gust velocity

3. Vertical wind velocity was computed using the following equation:

$$W_g = V(\alpha - \ddot{\alpha}) - V\int_0^t (\mathring{\theta} - \bar{\mathring{\theta}})\,dt + l\,(\mathring{\theta} - \bar{\mathring{\theta}}) + \int_0^t (a_n = \bar{a}_n)\,dt$$

where: w_g = vertical wind velocity, ft/sec

V = True airspeed, ft/sec

l = Distance from the angle-of-attack vane to the normal accelerometer, ft

a_n = Normal acceleration, ft/sec^2

α = Angle-of-attack, radians

θ = Pitch angle, radians

$\dot{\theta}$ = Pitch rate, radians/sec

A bar over a symbol denotes an average value with the average being taken over the entire penetration.

4. The foregoing equation is based on the following assumptions:

a. All disturbances are sufficiently small that the angle in radians may be substituted for the sine of the angle.

b. Boom bending is negligible.

c. The effect of variations in upwash on the vane-indicated angle-of-attack are negligible.

5. The vertical wind velocity data for all penetrations were lumped together and a frequency distribution was prepared for 5 ft/sec intervals from 0 to 65 ft/sec. Everything over 65 ft/sec was lumped in a single interval. Relative frequencies were calculated for each interval and then summed from high to low velocity.

6. Derived gust velocity was computed from the following equation:

$$U_{de} = 2Wa_n/m \rho_o SV_e K_g$$

where: W = Weight of aircraft, pounds

a_n = Normal acceleration, g's

m = Slope of wing lift curve per radian

ρ_o = Air density at sea level, slugs/ft^3

S = Wing area, ft^2

V_e = Equivalent airspeed, ft/sec

K_g = Gust alleviation factor, dimensionless

and:

$$K_g = 0.88 \ \mu_g/(5.3 + \mu_g)$$

$$\mu_g = 2W/m\rho \ CSg$$

where:

ρ = Air density (local), slugs/ft^3

c = Wing mean chord, ft

g = 32.2 ft/sec^2

7. The equation for U_{de} is based on the following set of assumptions:

a. The aircraft is a rigid body.

b. Aircraft forward speed is constant.

c. The aircraft is in stabilized level flight prior to gust entry.

d. The aircraft can rise (or descend) but cannot pitch.

e. The lift increments of the fuselage and horizontal tail surfaces are negligible in comparison with the wing lift increment.

f. The gust velocity is uniform across the span of the wing and is parallel to the vertical axis of the aircraft at any instant.

g. The gust has a (1 - Cosine) shape.

8. U_{de} was computed and tabulated at 10 samples per second. Then a discrete gust treatment was applied in that the maximum absolute value of U_{de} was selected from each interval between zero crossings. The interval between zeros was considered a single gust with the maximum U_{de} within the interval as its value. Based on work done with the F-100F several years ago a determination of acceptable stabilator rates was applied to the U_{de} data. Above a certain rate of stabilator movement the aircraft response to the control input generates an unacceptable error in normal acceleration. Such data points must be deleted to prevent bias of the U_{de} extrema and distributions. The threshold rate was a movement of 0.5 degree in 0.3 second. Above this rate all data was deleted.

SECTION VIII

DATA REDUCTION - 1974

Data reduction procedures were essentially the same for 1974 as for 1973 with the addition of two items. Roll attitude was recorded in 1974 and was used to correct the normal acceleration values for both true and derived gust velocity. Also, a term w_0 was added to the vertical wind velocity equation to provide for an initial vertical velocity at the start of the penetration. This term was assumed to be zero in 1973.

SECTION IX

TEST RESULTS AND DISCUSSION

Data Acquisition and Correction

1973

1. Ten test missions were flown during the period 23 May to 16 June 1973. The test aircraft made a total of 35 thunderstorm penetrations. Seven of these penetrations were rendered unusable for the following reasons:

a. Three penetrations were lost when the project pilot erroneously turned the tape recorder off upon exiting a storm and failed to recognize it. Three more penetrations were made before he noticed that the "record" light was out.

b. Two penetrations were lost due to a recorder malfunction.

c. One penetration was thrown out because, though the test aircraft was in the clouds, the final vector given by Rough Rider Control missed the storm.

d. An additional penetration was thrown out because the target storm was almost completely dissipated and no significant turbulence was encountered.

2. The data for the remaining 28 penetrations were acceptable with the exception of two parameters; normal acceleration and indicated airspeed:

a. Tabulated values of normal acceleration were observed to be consistently low. This was discovered after completion of the program. A check was made of the accelerometer but no malfunction was found. Acceleration data taken while the aircraft was on the ground were examined and found to be consistently low. Therefore, an average error was computed by comparing these data with the expected value of 1.0 g. For want of a better method, the assumption was made that the error was constant throughout the operating range of the accelerometer and a correction constant was added to all tabulated values of normal acceleration.

b. The indicated airspeeds tabulated from the flight tapes were, in some instances, 20 to 30 knots below those indicated in the cockpit. When the airspeed transducer was examined it was found to have drifted considerably from the pretest calibration. It was recalibrated and the corrections were applied to the tabulated data. The resulting airspeeds agreed much more closely with the cockpit readings.

1974

3. Three test missions were flown during the period 16 to 28 April 1974 and seven test missions were flown during the period 15 to 31 May 1974. The test aircraft made a total of 55 thunderstorm penetrations. No penetrations were lost due to instrumentation malfunction or procedural error. However, seven penetrations were deleted from the final data analysis because the final penetration vector missed the storm or because the storm had dissipated to the point where it could no longer be considered a storm.

4. During data reduction some problems were encountered with the normal acceleration and total temperature channels. Both parameters exhibited a regular sinusoidal variation in amplitude. Investigation revealed that this was an aliasing problem caused by 400-cycle noise which had been picked up by both channels. This problem was eliminated by running the data from both channels through a 40-cycle filter.

5. Another problem was the calculation of initial vertical velocity at the start of a penetration. The test aircraft was frequently in turbulence at the time of the start - penetration time hack and was sometimes in clouds as well. The possibility of a significant vertical velocity did exist. The only apparent method of calculating this velocity was to determine the rate of change of altitude over a short period at the beginning of the penetration. An attempt was made to average the altitude readings for the first second and the fifth second of the penetration, determine the difference, divide by the time interval, and call that the initial vertical velocity. A test was run to determine the lag in transducer response as a result of pressure variations at the static ports. The lag was negligible and could be ignored. The specifications called for an extremely low pressure response threshold, also. Still, there was considerable scatter in the altitude readings over a one second period. It was concluded that the variation was largely a function of electronic noise and possibly some vibration. The averaging method was not really satisfactory because one or two unreasonable values in a 10-value sample could greatly bias the result. Thus, an alternative method was selected which consisted of taking the median of the 10 values for each one second interval and using these to arrive at an altitude difference. This procedure was used to calculate all the initial vertical velocities.

6. A final object of concern during the 1974 program was the response of the gust vane and its interaction with the nose boom. The vanes had been redesigned to reduce their weight and increase their resistance to hail impact damage. Their natural frequency for a given airspeed was unknown. The natural frequency of the installed nose boom had been measured and was between 14 and 15 cycles per second. The possibility of interaction needed to be investigated. Consequently, a wind tunnel test of the vanes was accomplished by Captain James Karam, a member of the faculty of the Air Force Institute of Technology. The results of this test are documented in AFIT TR 74-8. Captain Karam found the natural frequency of the vanes to be 15 cps at 300 KIAS, the penetration airspeed of the F-4 test aircraft. This

coincides so closely with the natural frequency of the boom that interaction definitely did occur. This information was transmitted to NSSL. After a period of analysis they decided that the frequency range of interest to them was low enough that the vane-boom interaction would not create significant bias.

Analytical Objectives

7. The original aim of this report was to investigate possible differences in the character of turbulence within severe thunderstorms as a function of altitude. Some work was done near Darwin, Australia during 1969, which is documented in Meteorological Study 23 published by the Australian Bureau of Meteorology, Department of Science. In this report it was found that the correlation coefficients for various combinations of parameters varied for penetrations made at different altitudes. A tentative conclusion is that the nature of the turbulence itself varied with altitude. Based on the Darwin study, the correlation coefficients tended to increase with increasing altitude, which presents the possibility that the turbulence at the lower levels within the Darwin Storms was more random than it was at the higher levels. Therefore, it was decided that data from penetrations of Oklahoma thunderstorms would be examined for similar trends.

8. The 1973 turbulence test provided a unique opportunity for such a study. Previous thunderstorm penetration programs had been conducted predominately at altitudes above 25,000 ft. The goal of the 1973 program was to concentrate on low level penetrations in the vicinity of 10,000 ft. However, the actual penetration altitudes were dictated by the storms themselves and by the ability of the plan shear indicator to resolve areas of shear in the horizontal wind. Most of the detectable shear during 1973 was much higher than 10,000 ft. In fact penetration altitudes ranged from 15,000 to 29,000 ft with the average (to the nearest 1,000 ft) being 20,000 ft.

9. Analysis of the data from the 1973 program was deemed inconclusive because of the relatively small sample size (only 28 usable penetrations) and, since the NSSL had already requested a follow-on test for 1974, the decision was made to combine the 1973 and 1974 data to increase the sample population.

10. Two significant changes were made in 1974. The test aircraft was changed from an F-100F to an RF-4C and the plan shear indicator was replaced with another type of display. Penetration altitudes ranged from 12,000 ft to 16,000 ft with the average (to the nearest 1,000 ft) being 14,000 ft. The difference in the resolving power of the doppler display may have been a factor in the detection of shear at lower altitudes for 1974, and the storms themselves may have been different in character than those of 1973. In any case, the difference in average penetration altitudes for these two years defeated the plan to combine the data therefrom. Therefore, 1974 was analyzed separately.

11. For purposes of comparison, data from the 1965 thunderstorm program were selected. These data were published in Technical Memorandum IERTM-NSSL 32 in a paper entitled "Association Between Atmospheric Turbulence and Radar Echoes in Oklahoma", by J. T. Lee. This Technical Memorandum was published in April 1967. The subject paper also deals with the 1964 penetration program but during that program most of the penetration tracks passed through the centers of the storms while in 1965 they did not. Thus, the conditions under which penetrations were accomplished in 1965 were more compatible with 1973 and 1974 criteria. The principal penetration altitude for 1965 was 37,000 ft. The test aircraft was the same F-100F used in 1973.

Discussion of Figures

12. Radar reflectivity (Z_e) data was provided by the NSSL in the form of radar overlays and computer tabulations of Z_e. From these, the reflectivity parameters were read or calculated.

13. Figure 1* compares the maximum vertical wind or draft velocity (w) with the standard deviation of vertical wind velocity for each penetration. A linear relationship exists between the two as is evidenced by the linear correlation coefficients; 0.826 for 1973 and 0.829 for 1974. The slopes of the least-squares fits for these two years differ: that for 1973 being 3.85, and that for 1974 being 2.46. In general, the magnitude of the vertical winds is greater in 1973 than in 1974 as shown in Figure 2. Figure 2 depicts the frequency of occurrence of a given vertical wind velocity for 10 N.M. of flight in storms. The probability of encountering a vertical draft of a given magnitude is everywhere greater for 1973 than for 1974 with the exception of the 0 to 5 ft/sec interval. Possible reasons for this exception are discussed in paragraph 19 of this section.

14. Figure 3 is a comparison of maximum derived gust velocity $(U_{de})_{max}$, with standard deviation of derived gust velocity σU_{de}. Again, a linear relationship exists. Comparison of 1973 and 1974 data with some 1965 data is shown in Table 1

TABLE 1

Linear Correlation Coefficients, Slopes and Intercepts for Plots of Maximum Vertical Derived Gust Velocity Versus Standard Deviation of Vertical Derived Gust Velocity for 1965, 1973 and 1974:

YEAR	CORRELATION COEFFICIENT	SLOPE	INTERCEPT
1974	0.667	2.40	+7.38
1973	0.723	4.57	+1.79
1965	0.890	3.77	-0.66

The years are listed in order of increasing average penetration altitude.

*Figures are located at the end of the report.

15. Figure 4 presents the frequency of occurrence of a given derived gust for 10 N.M. of flight in storms. It agrees with the trend of Figure 2 in that the probability of encountering a given derived gust velocity was greater for 1973 than for 1974.

16. Figure 5 compares maximum radar reflectivity factor, $(Z_e)_{max}$, within the storm to $(U_{de})_{max}$ for each penetration. Figures 6, 7, 8, and 9, respectively, present the distributions of σU_{de} versus:

a. $(Z_e)_{max}$ within the storm.

b. $(Z_e)_{max}$ along the flight path.

c. Maximum gradient of reflectivity, $(\frac{dZe}{dx})_{max}$, along the flight path.

d. Average gradient of reflectivity, $(\frac{dZe}{dx})_{Avg}$, along the flight path.

Table 2 lists the correlation coefficients for the data plotted in Figures 5 through 9 and compares them with similar coefficients from the 1965 program.

TABLE 2

Comparison of Correlation Coefficient for Several Pairs of Parameters for 1965, 1973 and 1974:

	1974	1973	1965
$(U_{de})_{max}$ vs $(Z_e)_{max}$ (Storm)	0.06	0.12	0.33
σU_{de} vs $(Z_e)_{max}$ (Storm)	0.38	0.12	0.52
σU_{de} vs $(Z_e)_{max}$ (Path)	0.07	0.67	0.22
σU_{de} vs $(\frac{dZe}{dx})_{max}$ (Path)	0.33	0.51	0.19
σU_{de} vs $(\frac{dZe}{dx})_{Avg}$ (Path)	0.30	0.79	0.09

17. Historically, the best turbulence correlation for a given season is usually obtained between σU_{de} and $(Z_e)_{max}$ for the storm. Therefore, this pair of parameters would be likely candidates for examination to determine the possibility of a trend relating changes in the character of the turbulence to changes in altitude. While the data in Table 2 do not necessarily support the trend of increasing correlation coefficient with increasing altitude, they do agree, in general, with a trend in the data from the Darwin Study. In the Darwin Study the standard deviation of normal acceleration was correlated with $(Z_e)_{max}$ in the storm. This is very similar to correlating σU_{de} with $(Z_e)_{max}$ (Storm) because U_{de} is directly proportional to normal acceleration. The pertinent data are shown in Table 3.

TABLE 3

Variation of Correlation Coefficients (Standard Deviation of Normal Acceleration Versus Maximum Radar Reflectivity of the Storm) With Altitude for the Darwin Thunderstorm Study and for the Oklahoma Thunderstorm Study:

DARWIN STUDY		OKLAHOMA STUDY	
Altitude	Correlation Coeff	Altitude	Correlation Coeff
5000'	0.88	14000' (1974)	0.38
18000'	0.23	20000' (1973)	0.12
35000'	0.87	31000' (1965)	0.52

18. The correlation between $(U_{de})_{max}$ and σU_{de} tended to increase with altitude as shown in Table 1.

19. Both the vertical wind velocity and derived gust velocity data for 1974 may contain some aircraft dynamic response effects that have not been accounted for. A special test was conducted on the F-100F to determine its response characteristics and these were known quantities. The RF-4C has not been subjected to a similar evaluation. Furthermore the stabilator rates which apply to the F-100F for the removal of erroneous U_{de} values may not be correct for the RF-4C, though the same rates were used for both years. There is also a possibility that the gust vane - nose boom interaction might tend to inflate the frequency of occurrence values in the lower vertical wind velocity intervals. This might contribute to the cross over in the 0 to 5 ft/sec interval in Figure 2.

20. No consistent trends or correlations have been detected in the data. For this reason it is not possible to draw specific conclusions. It is hoped, however, that this document with the computations and data plots and the description of the methodology will be of value to future investigators of turbulence phenomena.

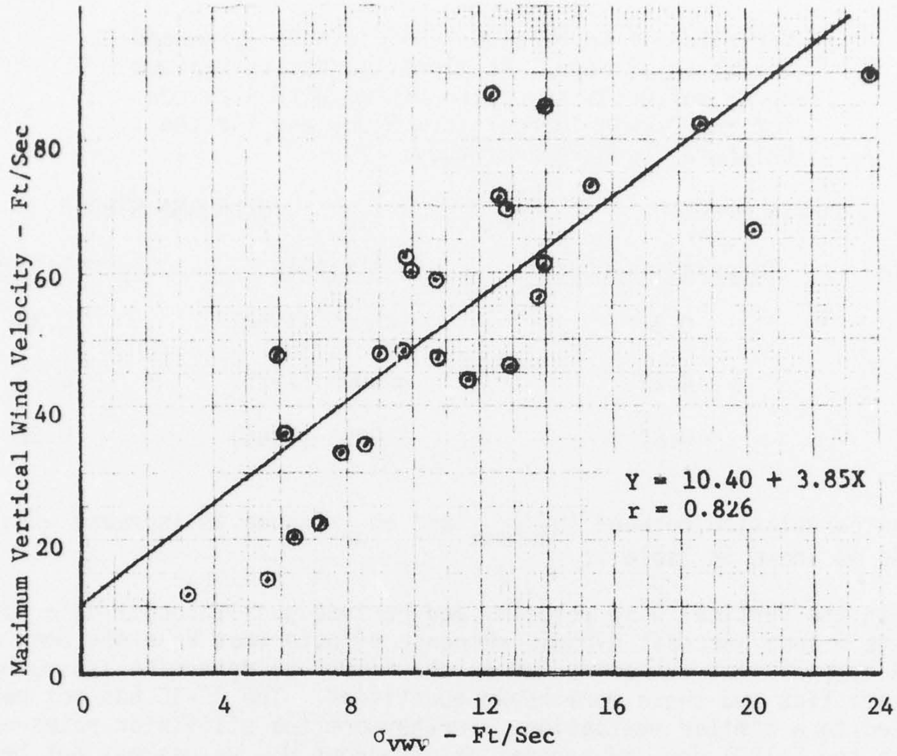

FIGURE 1a - Vertical wind velocity versus standard deviation of vertical wind velocity for 1973.

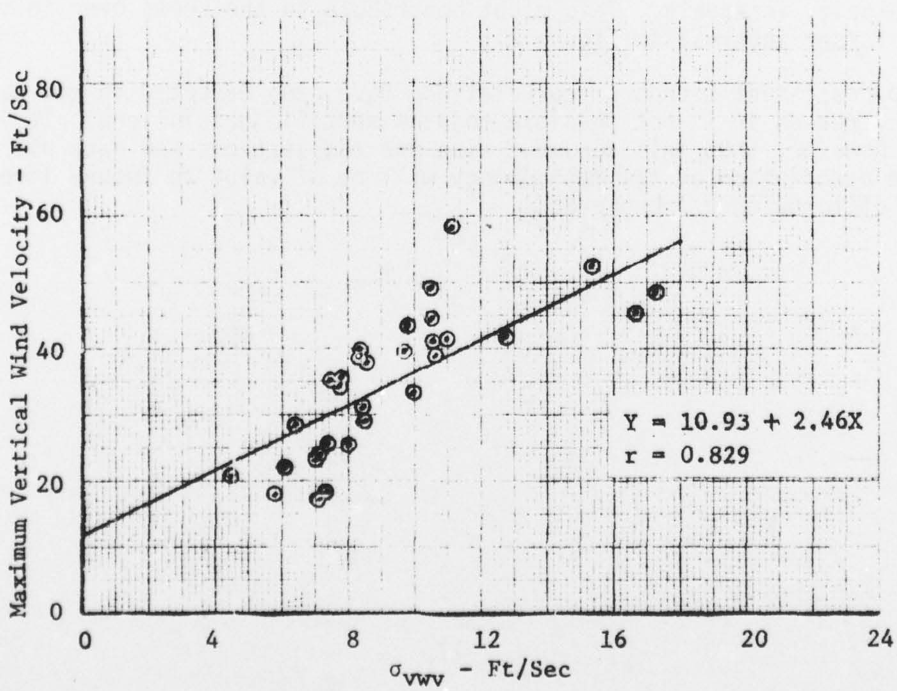

FIGURE 1b - Vertical wind velocity versus standard deviation of vertical wind velocity for 1974.

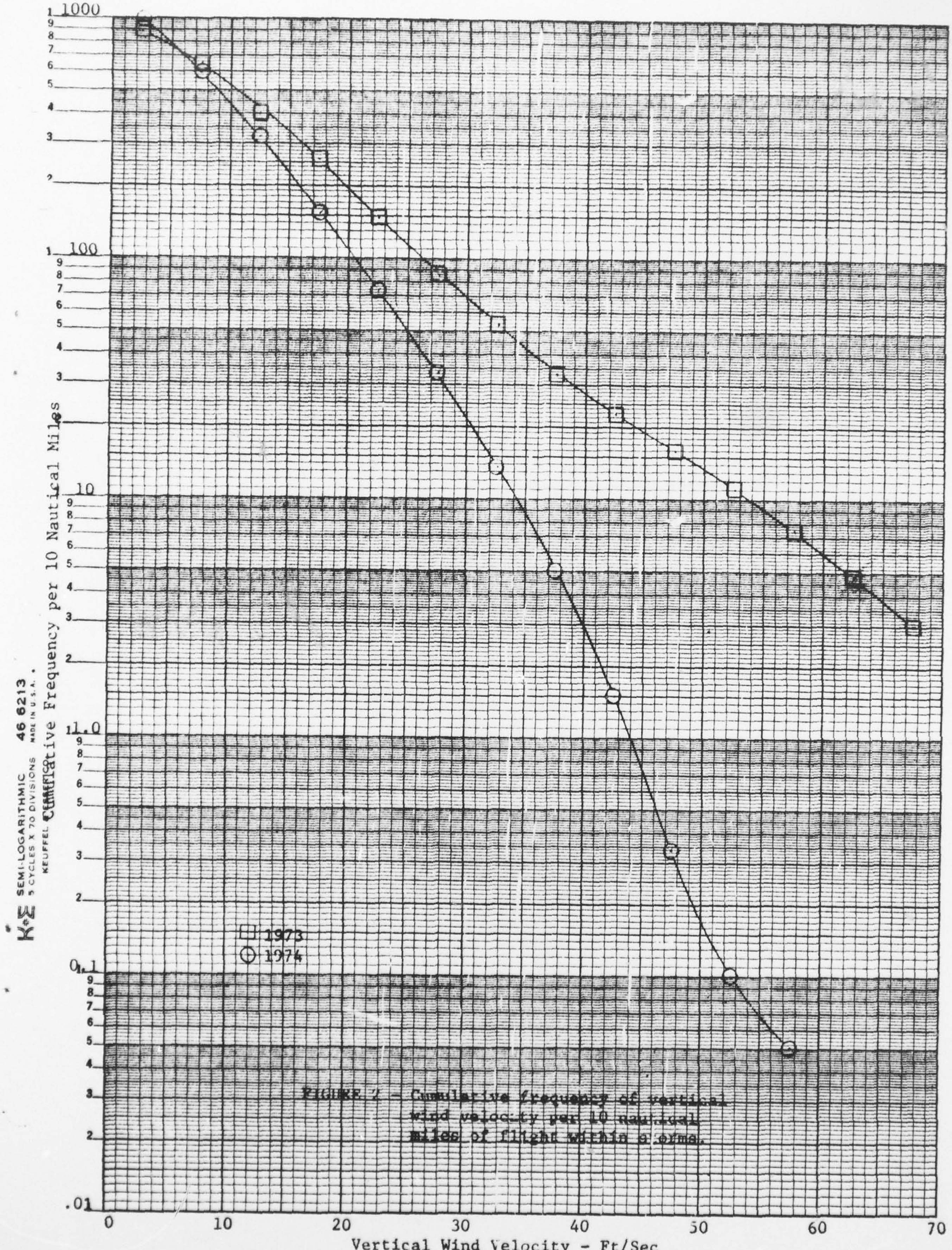

FIGURE 2 - Cumulative frequency of vertical wind velocity per 10 nautical miles of flight within storms.

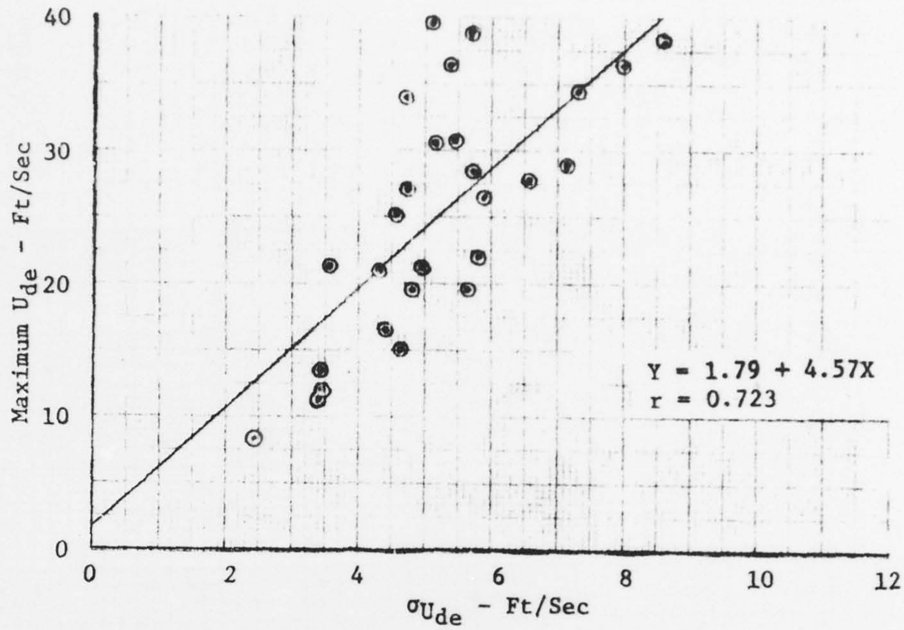

FIGURE 3a - Standard deviation of vertical derived gust velocity versus maximum vertical derived gust velocity for each penetration for 1973.

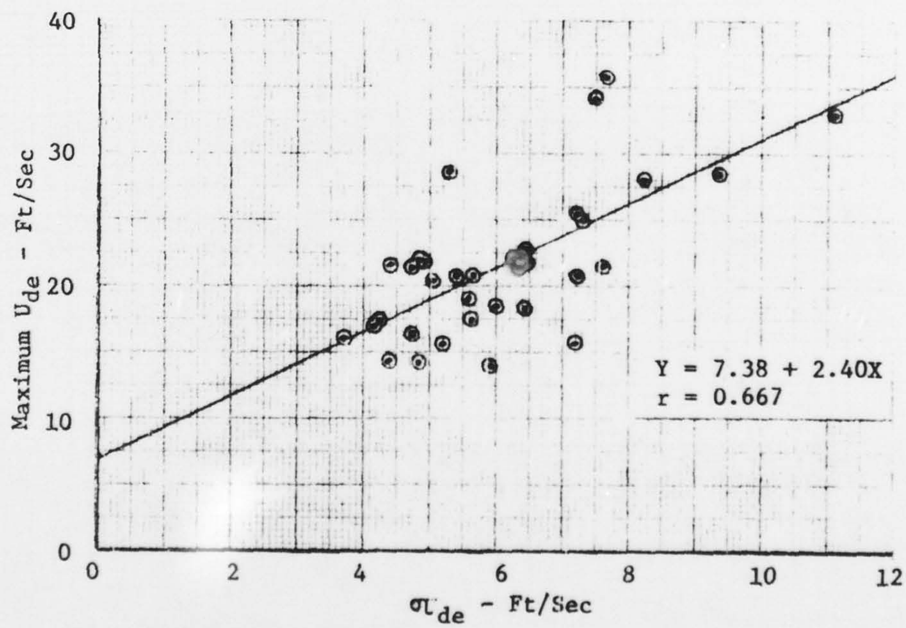

FIGURE 3b - Standard deviation of vertical derived gust velocity versus maximum vertical derived gust velocity for each penetration for 1974.

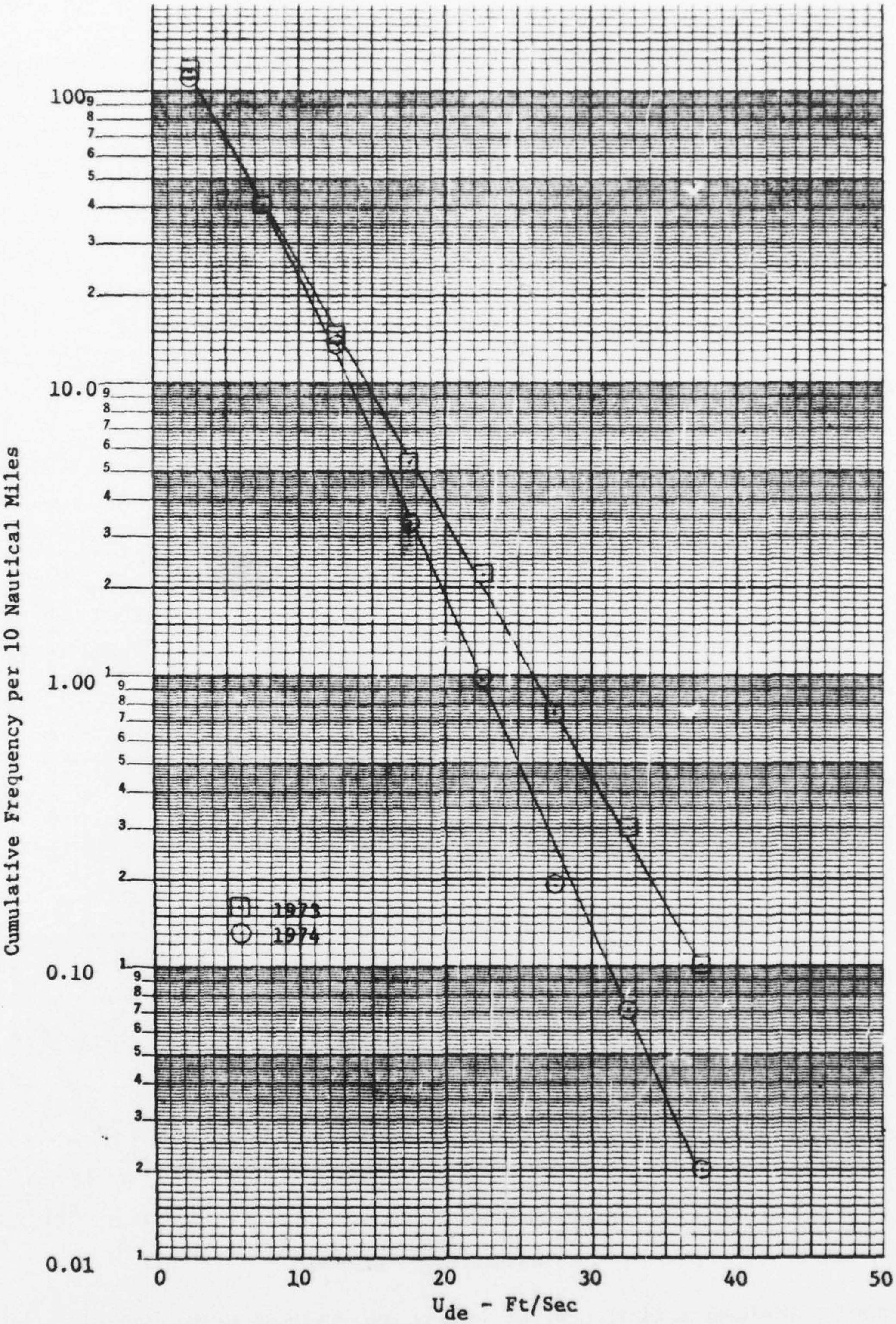

FIGURE 4 - Cumulative frequency of vertical derived gust velocity per 10 nautical miles of flight within storms.

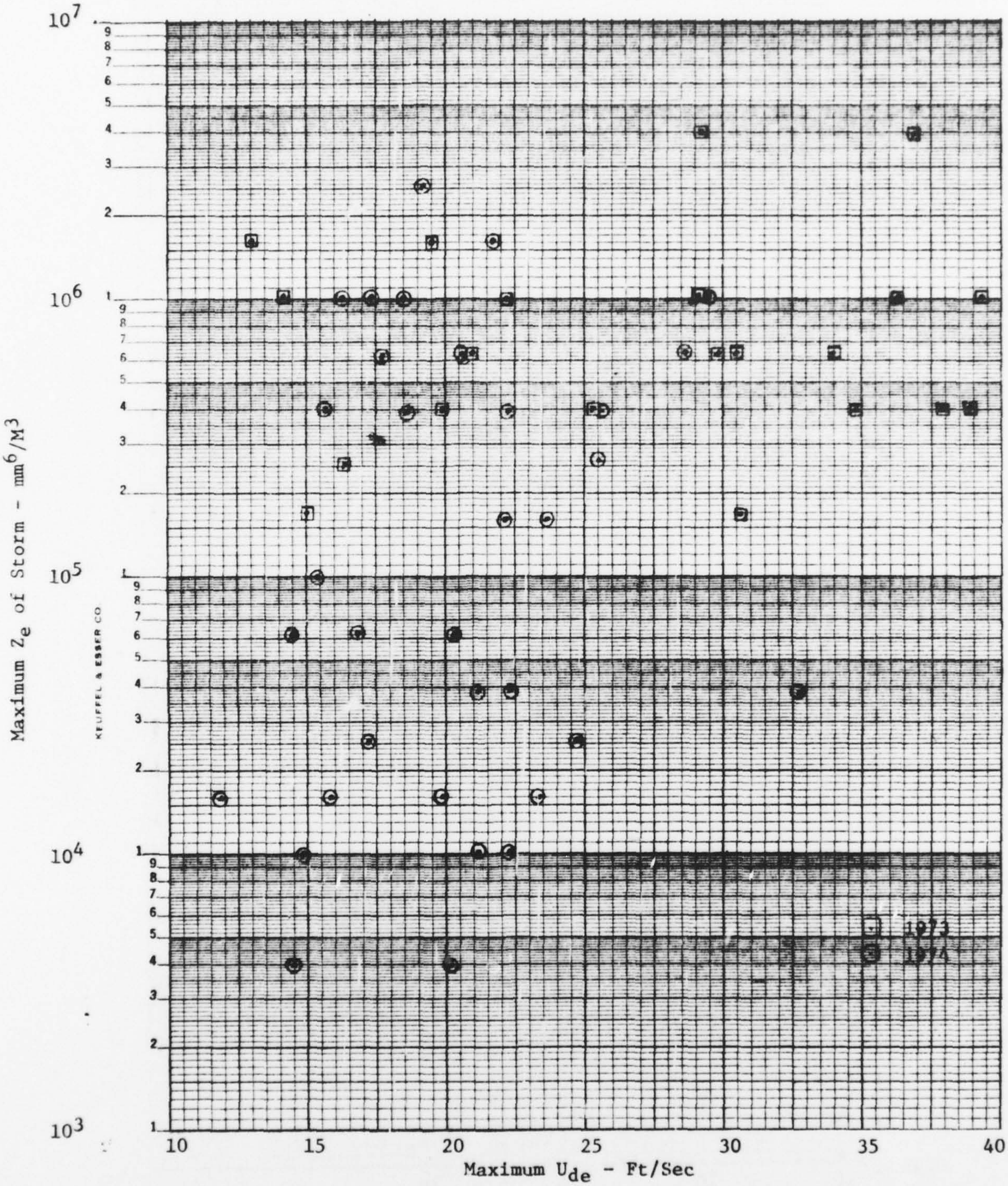

FIGURE 5 - Maximum vertical derived gust velocity versus maximum radar reflectivity of the storm for each penetration.

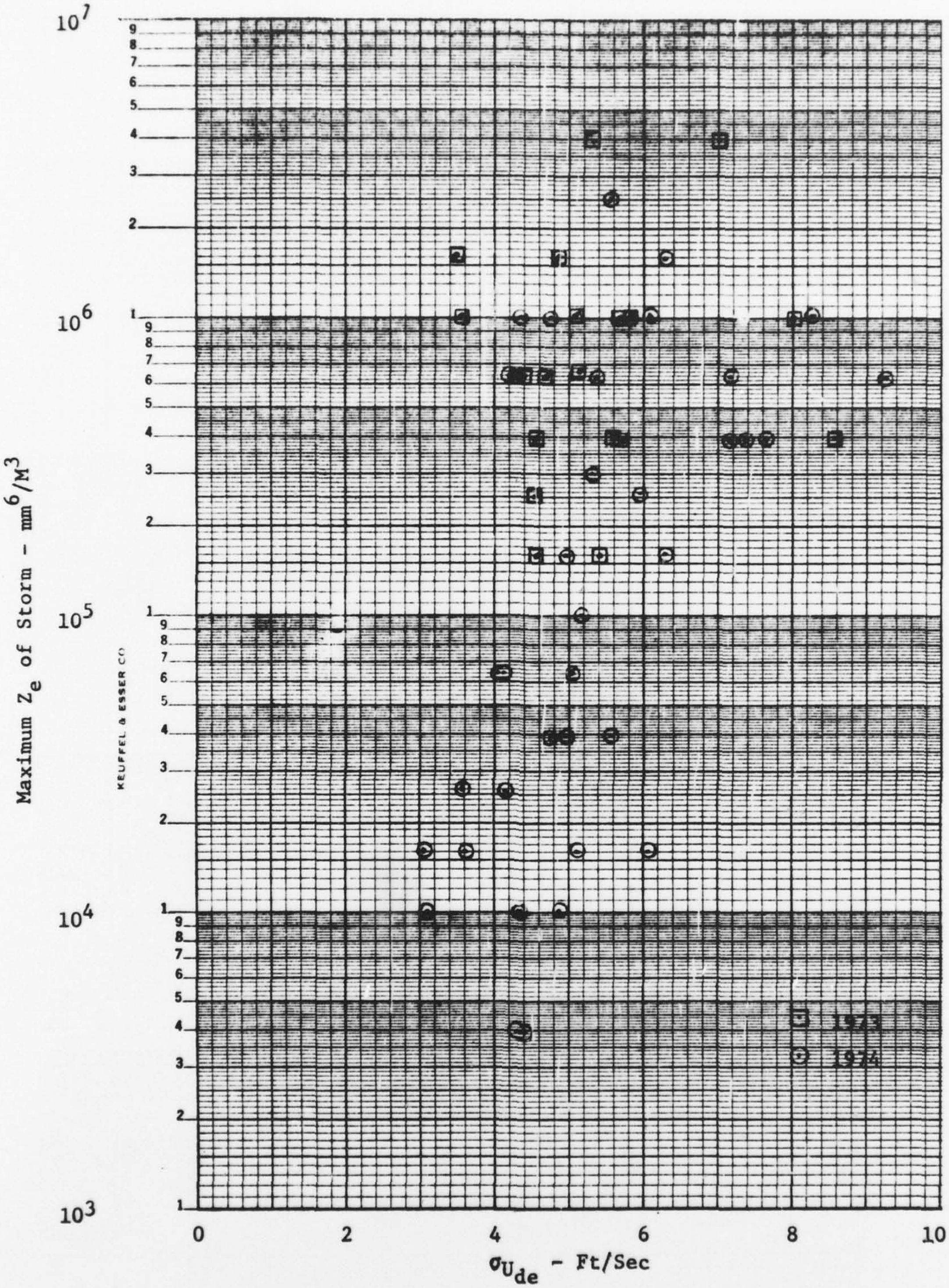

FIGURE 6 - Standard deviation of vertical derived gust velocity versus maximum radar reflectivity of the storm for each penetration.

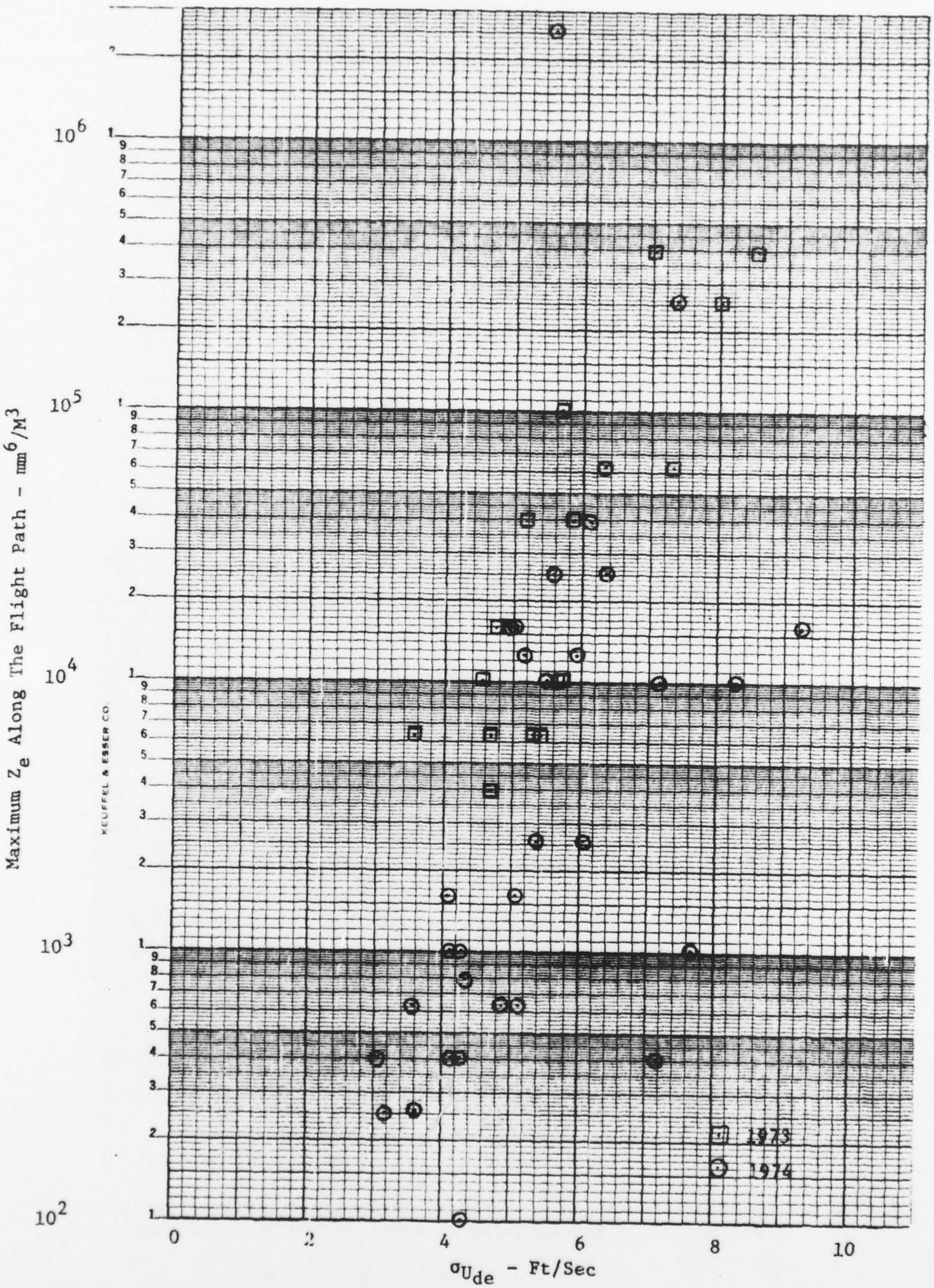

FIGURE 7 - Standard deviation of vertical derived gust velocity versus maximum radar reflectivity along the flight path for each penetration.

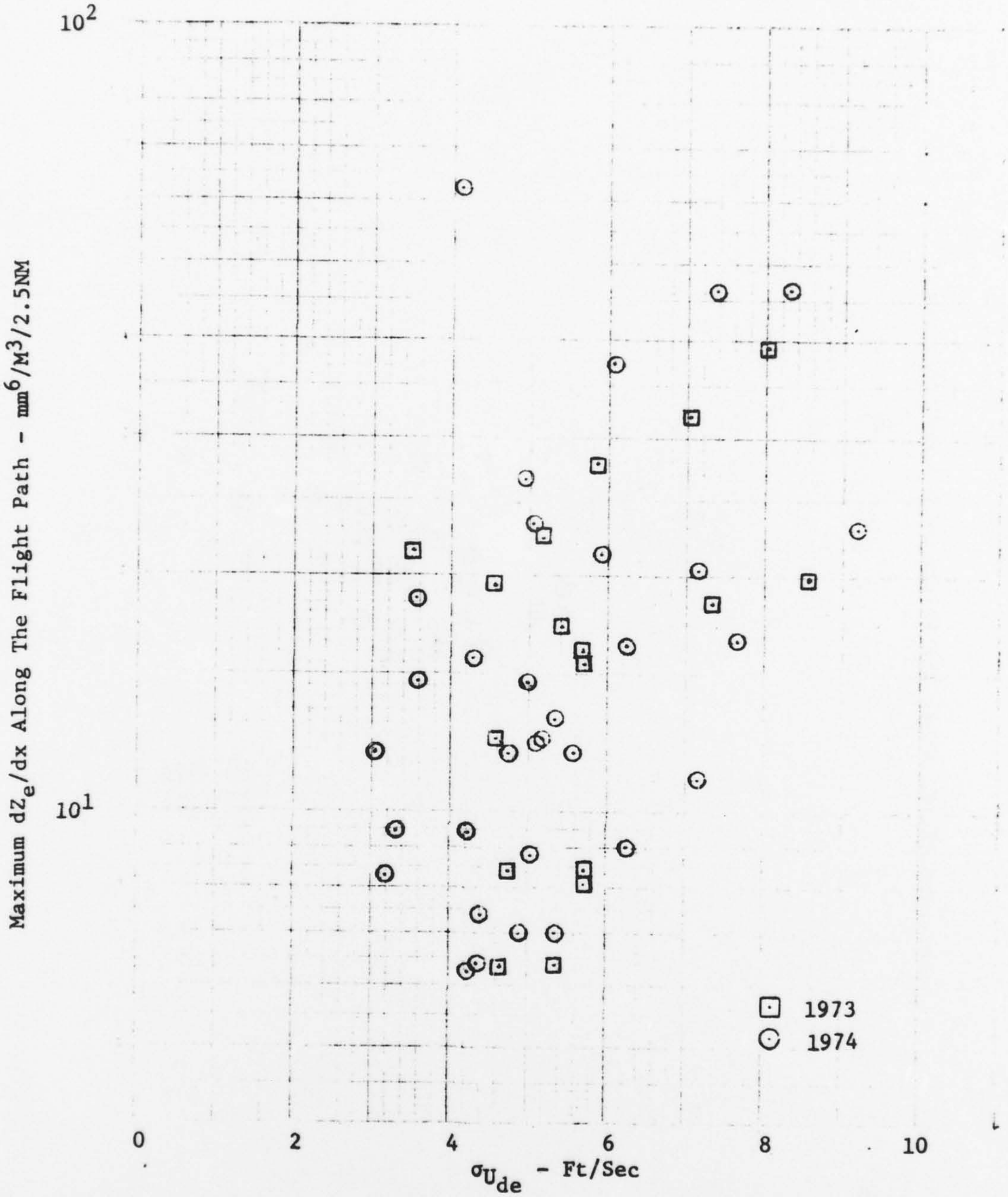

FIGURE 8 - Standard deviation of vertical derived gust velocity versus maximum gradient of radar reflectivity along the flight path for each penetration.

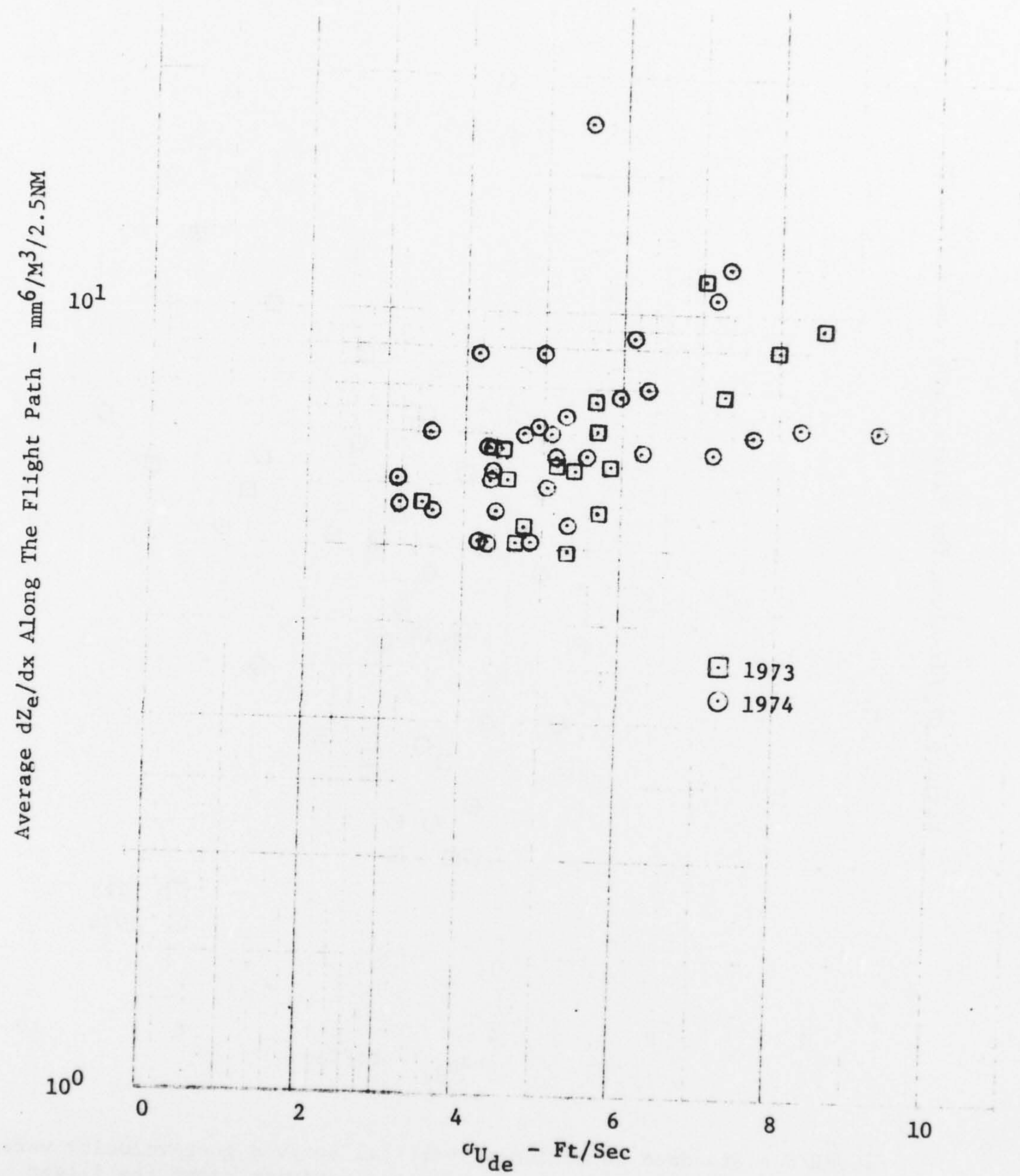

FIGURE 9 - Standard deviation of vertical derived gust velocity versus average gradient of radar reflectivity along the flight path for each penetration.